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Flashover process analysis of non-uniformly polluted insulation surface using experimental design methodology and finite element method

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ABSTRACT

Conclusions about flashover process of non-uniformly polluted insulating surface may be drawn widely on the basis of laboratory experimental studies. However, these conclusions could be supported by simulation results on the E-field stress distribution. This paper presents a study of the flashover voltage, the maximum E-field and the breakdown strength of the non-uniformly polluted insulating surface. Three parameters of pollution layer were taken into account: the conductivity, the length and the position. The experimental design methodology is adopted in this study. Parameters main and interaction effects have been evaluated using the variance analysis technique. Results show that the flashover process is mainly influenced by the length of pollution layer, however, the effect of conductivity is limited on the accelerating the flashover process, which in-turn reduces the breakdown strength. As conclusion, the simulation based on the finite element method combined with the experimental design methodology found to be very efficient tool to understand the flashover process of non-uniformly polluted insulating surface. The obtained information could be exploited to better understand the flashover process as well as to improve the insulation flashover testing standard under laboratory simulated conditions.

1. Introduction

The socio-economic impact of power system outages due to the HV insulators pollution represents a major concern for the electric power utilities [1,2]. Therefore, more attention has been paid recently to this subject because of its importance and complexity. Consequently, several models, norms and test guidelines have been proposed to avoid the dramatic consequences of power system outages related to pollution flashover of HV insulators [3–9]. Usually, Insulating surface is affected by contamination deposits comes from air-borne, when humidity, fog or wet reach certain level, conductive electrolyte covers the insulating surface, which results in leakage currents flow, heating effect caused by these currents evaporates the water and leads to dry bands formation in regions where the current density is the highest. The E-field stress supported by the whole insulator will be supported by those dry bands, the maximum E-field value in the junction air-electrolyte increases, once the ionization level in this air is reached, avalanche starts and surface electric discharge bridging the dry band occurs and its elongation leads to a total flashover of insulator [10].

Dry bands formation on the surface of polluted and wetted insulator is an important precursor to the appearance of surface electric discharges that can develop into total flashover when the potential gradient surpasses the breakdown strength [1]. For non-uniform polluted surface, excessively high E-field stress occurs at the junction of two different surface resistivities, the larger are the dry band created on the surface, the lower are the stresses at its edges. Moreover, the location of a dry band has a weak influence on the E-field strength at the dry band edges [11]. It is also shown that the E-field stress increases with increasing the pollution level and the highest stress was noticed at the junction of the shed and sheath region because of the small radius of curvature as compared to the tip of shed. Moreover, it was observed that the increase of pollution severity has a weak increasing effect on the linear distribution of electric potential along the insulator surface [12]. Moreover, it was noticed that the high E-field stress at the energized end and at the junction of shed and sheath region may lead to dry bands formation in these regions due to the high power dissipation and resultant joule heating effect. The effect of pollution layer thickness on E- field distribution is investigated, it was found that the max-

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imum E-field increases for thicker pollution layer deposited along the insulator leakage path [13–15].

Most of the previous studies on the flashover phenomena were based on the analysis of real insulators, which present the inconvenient of reproducibility under laboratory pollution conditions, in addition to the difficulty of pollution layer control. Therefore, many plate laboratory models have been proposed by different researchers, these plate models allow better control of pollution repartition and provide general understanding of the flashover mechanism [16–19]. Flashover mechanism of polluted insulator depends on its resistance against the E-field stress, therefore, the analysis of the E-field intensity on the insulating surface is very important to understand the insulation flashover process, however, most of proposed studies supposed an uniform pollution layer on the surface, which will prevents the distortion of potential distribution, thus neglecting the high E-field stresses created in pollution-air junctions [12,20]. Therefore, studying the non-uniform pollution effect on the flashover process can be very useful during the insulation design, parameter optimization and flashover elimination, which can be achieved through the correlation of findings on flashover voltage, maximum E-field stress and breakdown strength analysis [21–25].

Calculation of E-field generally should be precise and requires higher accuracy, because the maximum field strength is usually the most important and decisive value in insulation design and discharge studies. Therefore, numerical methods chosen for computation should be simple to apply, fast in computation and capable of yielding accurate results. Finite element method (FEM) is one of the powerful methods in giving precise solutions to electric field problems of high voltage insulation [15,16,20,24,25].

Laboratory experiments concerning breakdown and flashover phenomena used for insulator design and testing are time-consuming and have further obstacles, such as high cost, time and the need for special equipment [12,26]. Usually, One-factor-at-time (OFAT) is the most common approach in designing experiment in order to determine any response variation. This classical experimental method involves changing one variable and keeping the others at fixed condition. OFAT is simple to plan and execute but it is inefficient when it comes to two or more independent variables. In addition, it also faces difficulties in defining interaction between independent variables. In this regard, design of experiment (DoE) is a valuable technique for multi-factor experiments because it reduces the number of test runs since the investigated factors vary simultaneously. Eventually, the relevant expensive and time consuming experimentation and simulation tests can be omitted, or, at least, limited in the absolutely indispensable number [27,28]. Then, the mathematical processing of data allows an accurate evaluation of factor effects and interactions as well as to develop a relationship between the influencing factors and the response of the process.

In this paper, we correlated the experimental and simulation findings of the flashover voltage of non-uniformly polluted insulating surface. Specifically, the effects of non-uniform pollution layer parameters namely, conductivity, length and position, on responses called, the flashover voltage, the maximum E-field and the breakdown strength are investigated using laboratory experimentation and FEM simulation, the design of experiment methodology is adopted to reduces the tests number and to give more significance to results, then, the analysis of variances (Anova) is adopted to evaluate the contribution of the studied factors and their interaction on the total variation of the studied responses. Finally, we correlated the responses corresponding to the same experimental test run, which allows integration of useful conclusions on the flashover mechanism. This study provides a lot of useful information for whom working on the investigation of non-uniform pollution flashover mechanism.

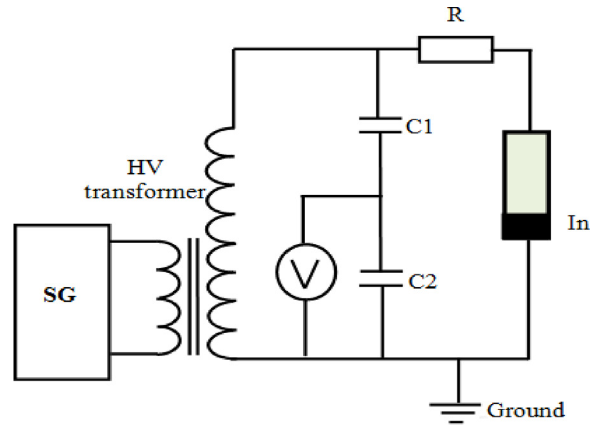

Fig. 1. Experimental setup, SG: voltage control unit (OT 276), HV transformer, R: current limiting resistor (2.5 MΩ), V: voltage measurement (DMI 551), C1 and C2: capacitive voltage divider (100 pF), In: insulator model.

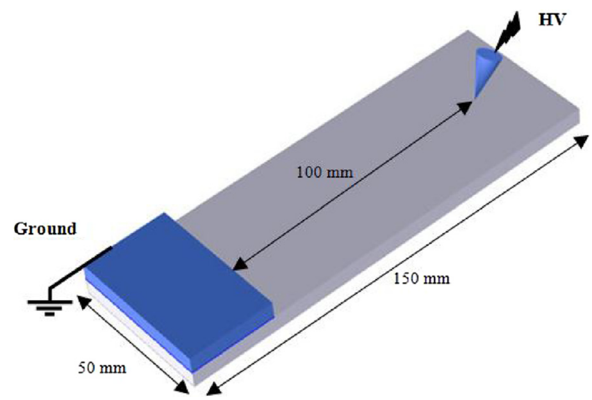

Fig. 2. Studied insulator model.

2. Material and methods

The experimental setup used in this work is shown in Fig. 1. It consists of a test cell, AC voltage source, regulating transformer, a HV test transformer provided by HAEFELY (5 kVA, 100 kV, 50 Hz), the applied voltage is controlled by OT 276 control panel, digital measuring instrument DMI 551 is used to record the flashover voltage. The test specimen is shown in Fig. 2, it consists of a plane model made of glass having 6 mm thickness, 50 mm width and a total length of 150 mm. The ground electrode is formed by a rectangular band of steel in touch with the test model. The HV electrode is formed by a point made of steel. The total leakage distance between energized and ground ends is equal to 100 mm. The pollution layer consists of a solution prepared by mixing of one liter of distilled water with an adequate quantity of NaCl, different solutions of different conductivities were prepared using a conductimeter. Firstly, the insulator is cleaned up with water then dried using paper tissue. Then, it is well cleaned with alcohol to insure the perfect neatness of the studied model. Spraying technique is used to obtain the desired repartition of non-uniform pollution layer on the surface [3,29], the non-uniform pollution layer configurations in Fig. 3 are achieved by covering the region that we want to save clean, then, 5 pulverizations were applied from a distance of 50 cm using an adequate sprayer, this technique allows a good reproducibility of pollution layer within a thickness average of 2 mm. The studied parameters of non-uniform pollution and their levels are indicated in Table 1. The applied voltage was increased using constant speed of the slope until the flashover occurs. This process was repeated for all configurations indicated in Table 2. In order to realize a reliable